

The seal of the Department of Defense is centered in the background. It features an eagle with wings spread, holding an olive branch and arrows, with a shield on its chest. The eagle is surrounded by a circular border containing the text "DEPARTMENT OF DEFENSE" at the top and "UNITED STATES OF AMERICA" at the bottom. The seal is rendered in a light, semi-transparent blue and yellow color.

**Joint Directed Energy  
Transition Office  
(DE JTO)**

**Directed Energy Professional Society**

**DE JTO Remaining Relevant**

**Dr. Lawrence Grimes, Director  
23 March 2021**



# Challenges to Relevancy



- **HEL JTO and now DE JTO has been pushing the state of the art (SoA) of DE technologies for multi-Service & Agency (S&A) uses since 2001**
- **DE JTO funding has been ‘flat-lined’ since the 20% budget cut in FY13 and has experienced another significant budget cut in FY21 forcing a re-prioritization of activities and processes:**
  - Maintain normal DE JTO functions – keep office open
  - Work closely with OUSD & DEW Community of Interest (CoI) to show DE JTO relevance on the DE Roadmap
  - Focus on Beam Control / Fire Control technologies and support lethality and database initiatives
  - Postpone HPM and other technology development efforts

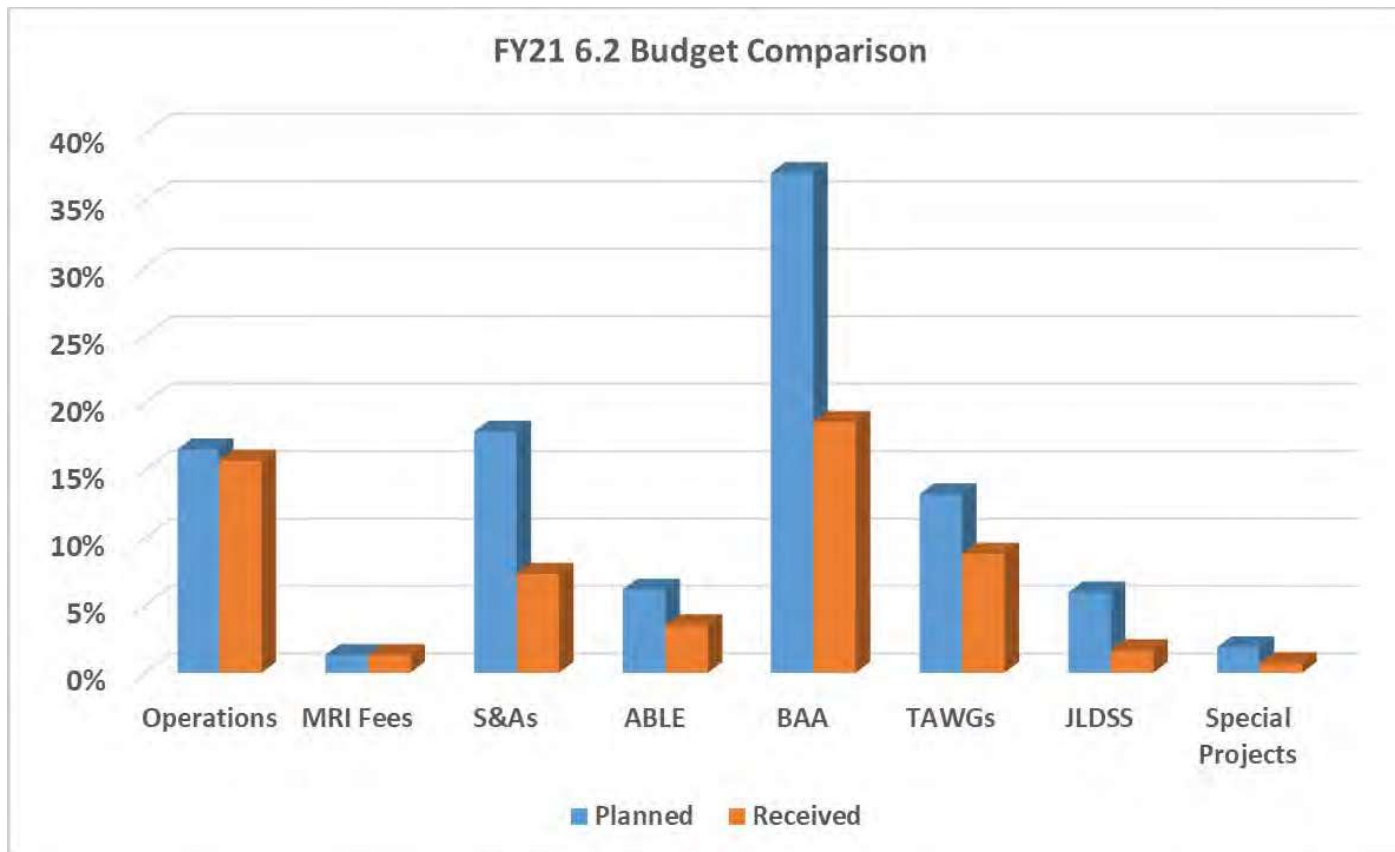


# DE JTO FY21 Funding Issue



FY-21 6.2 budget line reduced by ~\$21M required re-prioritization

- Postpone HPM BAA awards
- Reduce Service and Agency awards
- Terminate some 2<sup>nd</sup> / 3<sup>rd</sup> year efforts





# Strategic Investment Plan



- **OUSD(R&E) High Energy Laser Scaling Initiative (HELSEI)**
  - Accelerating the development of Solid State Lasers (SSL) (100KW class - 300-500 KW class - 1 MW class) over the next 10 years; 5 contracts in place
- **DE JTO Joint Service Beam Control Investment Plan (BCIP)**
  - Robust 6.2 investment in Beam Control technology required to implement BCTA Report recommendations
  - And to Synchronize with HELSEI Development
    - Sequentially achieve BC Technology for 500KW Lasers (FY21-26); 1 MW Compatibility (FY26-28)
- **DE JTO BC Technology “Needs” Spreadsheet (FY21-26)**  
**Developed to:**
  - Summarize Major BCIP Technology Needs / Shortfalls
  - Capture Current HEL Investments (DE JTO / Service)



# Beam Conditioning, Tracking, and AO DE JTO ABLE Efforts Ongoing



Fast Steering Mirror (ATA)



→ ABL 2004

Deformable Mirrors  
(NG-AOX, MZA/AOS)



→ 2002-20

JHPSSL, ABCD, DLWS, HELCAP, MBCSIL, HEL TVD

Tracker (QinetiQ)

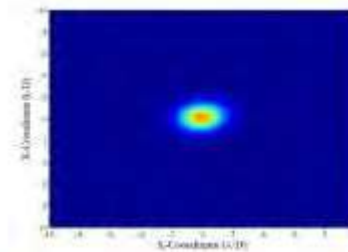


Tracker (Nutronics)



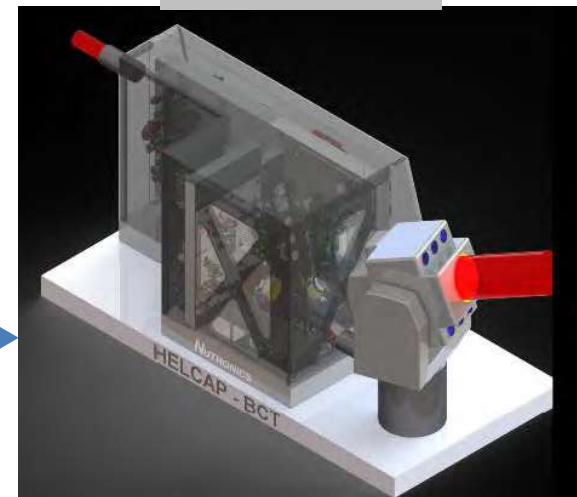
→ ETS 2020

95% Turbulence - ABCD



→ 2019

HELCAP BCT



ABLE / (ETS & ABCD) 2014-19





# Beam Control Technology Investment Categories (500 KW class lasers)



## **1. Automated Target Engagement Technology**

- Automated Target Engagements
- Wide Field of View (WFOV) Sensor
- Fast Beam Director Slew
- Target and Scene Generation Codes

## **2. Path Characterization System (PCS)**

- Provide Local Weather Sensors
- Maintain 24 hr. Weather Monitor (NWP)
- Derive Real-Time (RT) Propagation Path-Dependent Atmospheric Parameters
- Generate Target Scene from Model
- Estimate Beam Spot Size / Irradiance Profile on Target ( $\text{kW}/\text{Cm}^2$ )

## **3. Target Tracking**

- Track Illuminator Lasers (TILL)
- Track Camera
- Fast Steering Mirrors (FSMs)
- Tracking, Target Pose, and Aimpoint Selection and Maintenance Algorithms

## **4. Wavefront Compensation**

- Beacon Illuminator (BILL)
- Wavefront Sensing Cameras
- Deformable Mirrors (DMs)
- Advanced Wavefront Sensing Technology
- Thermal Blooming Compensation

## **5. Demonstration and Field Testing**

- Real-time Atmospheric Measurements
- Heavy Clutter Acquisition & Track
- Robust Low-SWaP Fine Tracking
- Aimpoint Selection & Maintenance



# DE JTO TAWGs Defining Beam Control / Fire Control Solutions

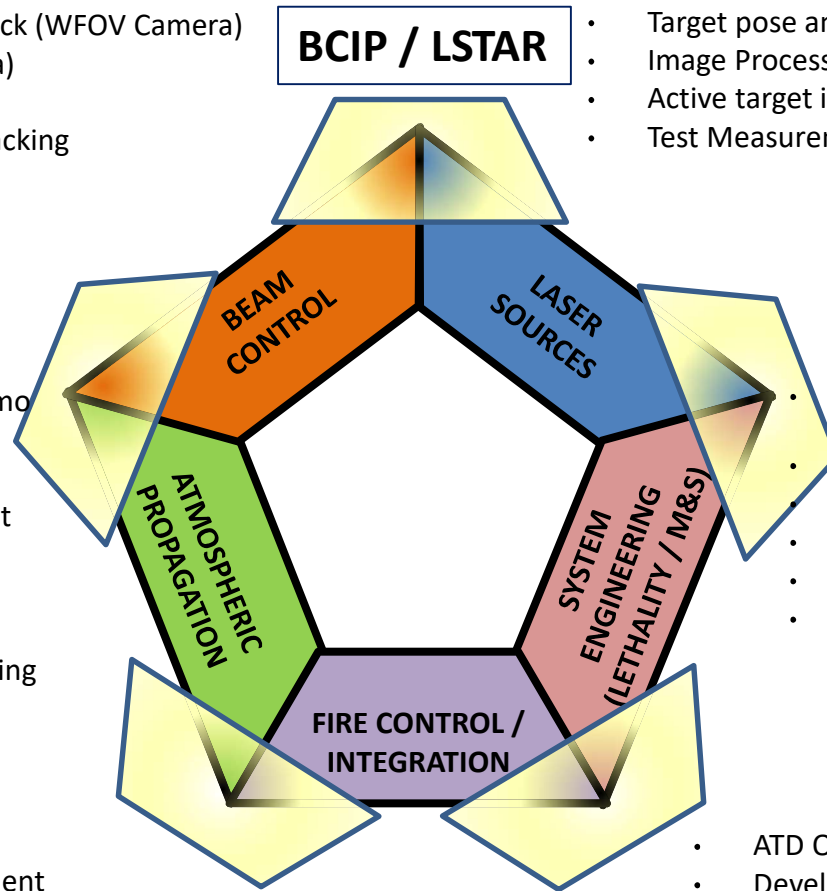


- Acquisition & Coarse Track (WFOV Camera)
- Fine Track (SWIR Camera)
- Algorithms
- Detection and coarse tracking
- Improved tracking

## BCIP / LSTAR

- Target pose and aimpoint selection
- Image Processing
- Active target imaging and scene generation codes
- Test Measurements / Diagnostics

- Define Path Conditioning System (PCS) requirements
- Support PCS Development for demo in 2025
- Support Test plan development
- Define Atmospheric Measurement requirements.
- Recommend Atmospheric Measurement Instrumentation
- Identify / run Atmospheric Modeling / Predictions



- Lead/Coordination of Demonstrator Review Products (e.g. SRR, PDR, CDR)
- System Performance Models (M&S)
- Vulnerability Assessment (Lethality)
- Vulnerability Module (VM)
- Detectable Effects
- Lead/coordinate Test plan development

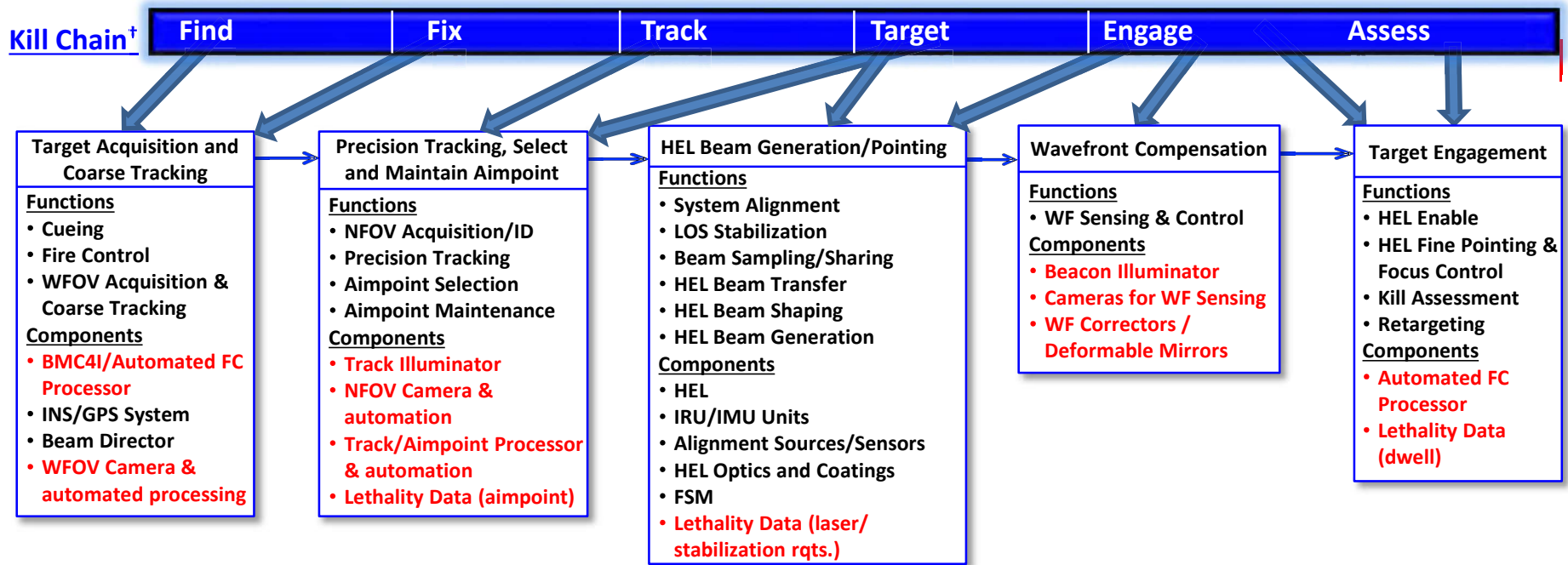
- Target Designation
- Target ID
- Autonomous Engagement
- Range Acquisition Sensor Interface/Handover
- PCS lead - integration and interface

- ATD Objectives Define Testbed requirements
- Develop "notional" autonomous engagement architecture
- Develop "candidate" DRMs (target parameters, range / altitude / velocity scenarios, atmospheric conditions..)



# HEL Kill Chain

## Sequence Functions & Components\*



- Under good conditions, engagement sequence is ~30 seconds – *need to drive much lower (10-15 second regime)!* The problem is considerably worse for supersonic targets!!
- Many of these components/functions are important and need additional S&T investment
- **High priority Tracking and Targeting technology areas needing additional investment in RED**

\* - Not all dependencies shown

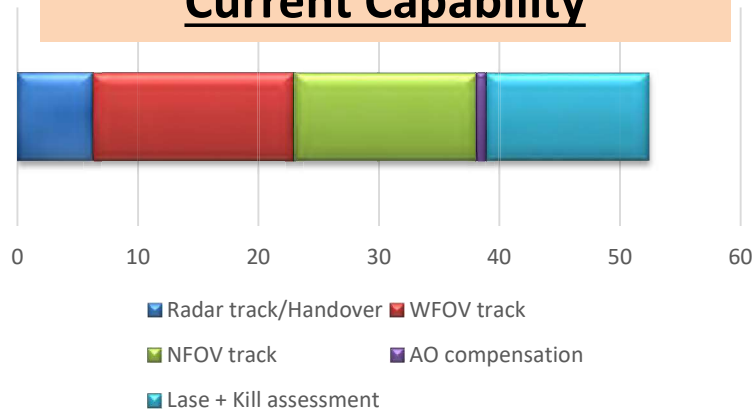
† - Notional timeline, based on 2020 DE JTO Beam Control Investment Plan (BCIP)



# HEL Autonomous Engagement

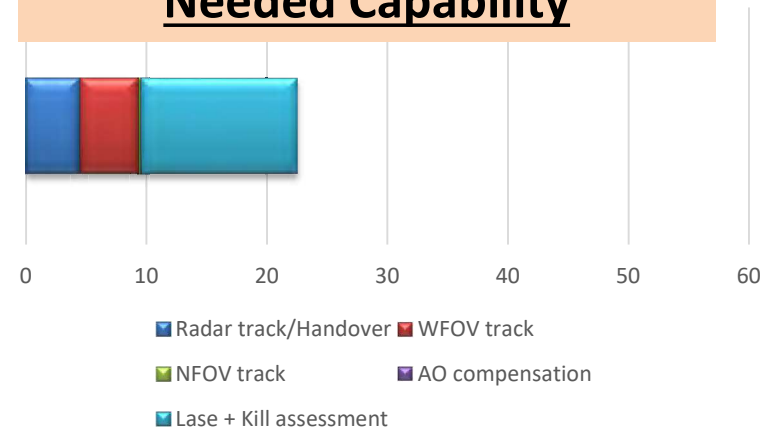


## Current Capability



- HEL Engagement of robust targets requires high operator workload
- Range limited by sensors / illuminators
- Manual target ID & aimpoint selection
- Lase duration based on visual damage assessment

## Needed Capability



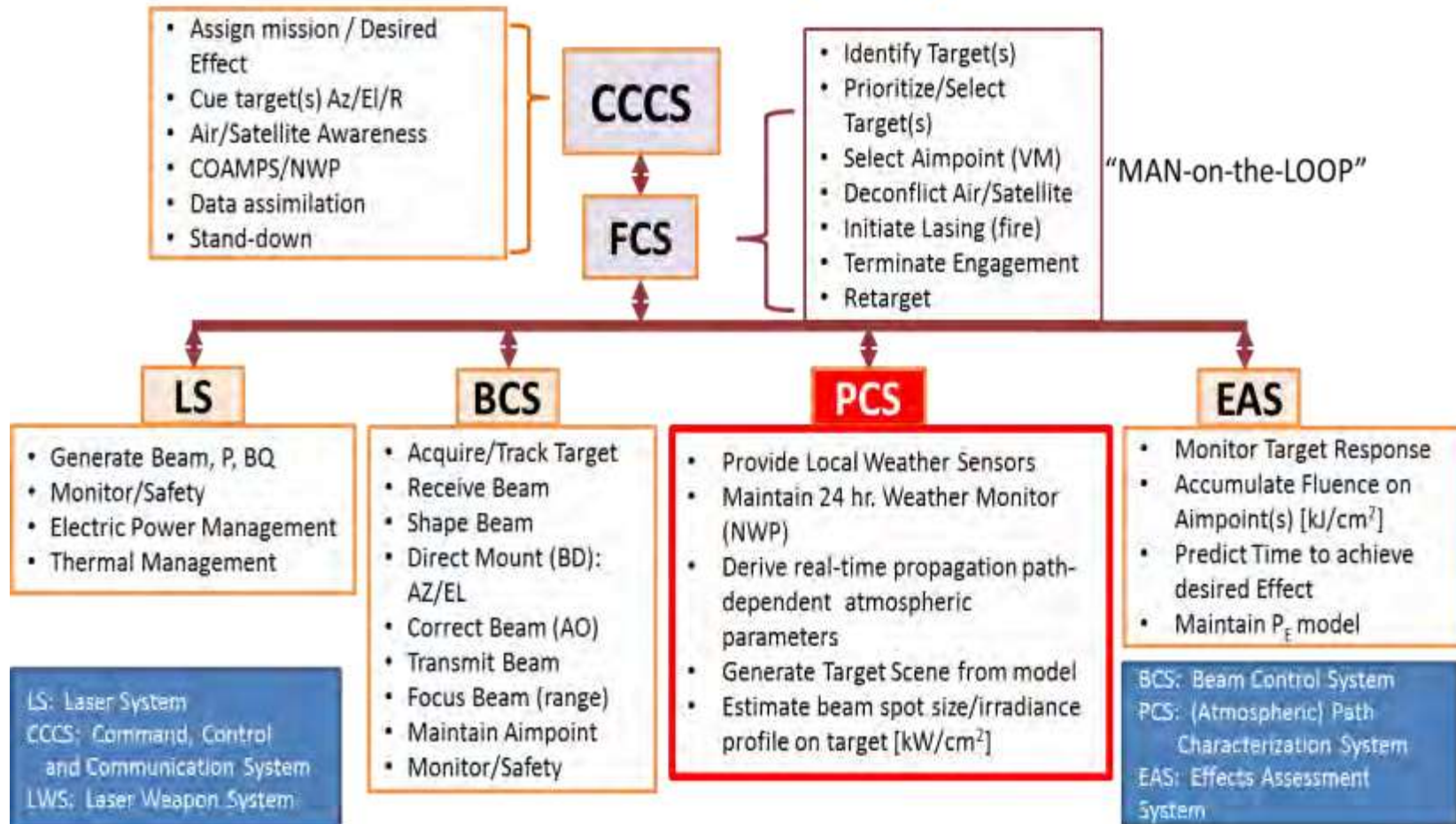
- Autonomous Fire Control
- Increased capabilities of sensor / illuminator
- Automated target ID and optimum aimpoint selection
- Predicted lase duration based on atmospheric propagation predictions, Vulnerability Module assessments.



# Path Characterization System (PCS) Enhances LWS Capabilities



## LASER WEAPON SYSTEM (LWS) ARCHITECTURE



**PCS provides confidence in LWS Effectiveness in all conditions/missions of interest**



# Targeting and Tracking Issues



- **Current HEL systems need improvement to address short timeline engagements**
  - Increased automation enables rapid engagements
  - Increased range for target acquisition and track enables more HEL time on target
- **Ability to track targets in high clutter environments and to accurately maintain a small laser spot on the aimpoint of the target is also a key enabler**

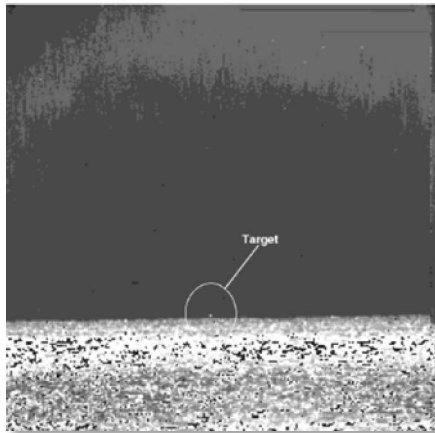
Issues with State of the Art	Recommendations
Difficulties acquiring target in high clutter	Improved sensor and image processing, multi-band/sensor
Man in the loop	Highly automated fire control with atmospheric path characterization
Limited engagement range	Higher power SWIR cameras and illuminators
Minimize beam movement on target (jitter and drift)	Higher power SWIR cameras and illuminators, improved trackers
Atmospheric turbulence driven beam breakup	High Rytov atmospheric compensation



# Tracking and Targeting Issues



## Discrimination of targets in clutter

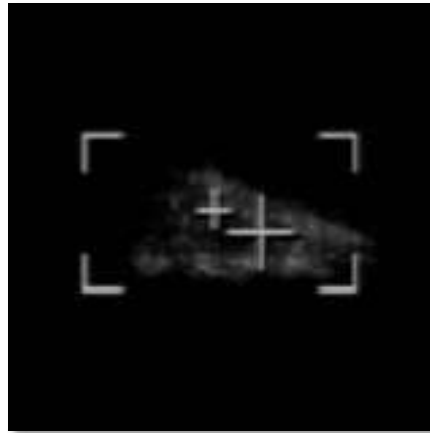


MWIR image of unresolved cruise missile in glint field

**Issue:** Difficult to extract cruise missiles in high cluttered environments.

**Remedy:** Address with better image processing and sensor fusion for target acquisition

## Passive imagery very dim

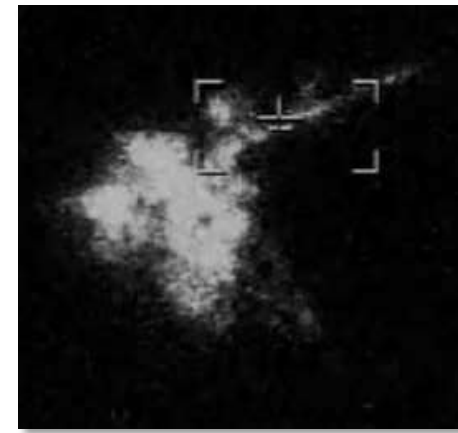


Laser illuminated image of small UAS

**Issue:** Images of the target can be very dim due to atmosphere and range.

**Remedy:** Address with more powerful illuminators and sensitive cameras

## Image degraded due to turbulence



Laser illuminated image of antenna on small boat

**Issue:** Atmospheric turbulence degrades images.

**Remedy:** Address with high Rytov adaptive optics to compensate



# DE Material Effects Repository (DEMER) Expanded to Encompass the Kill Chain



DEMER: Previous state was DE lethality repository

Kill Chain:	Find	Fix	Track	Target	Engage	Assess
Laser/HPM						
EO/IR Imager	EO/IR Imager					EO/IR Imager

DEMER has infrastructure and data storage/dissemination to support entire kill chain

## Vision

- Build user base across DE and EO/IR (incl KE) Community
- Establish imagery database for:
  - DEW tracking system development and evaluation
  - Training of AI based target recognition and aimpoint selection
- Establish atmospheric data (initially weather cubes) site on DEMER and correlate with imagery test data

Warfighter  
System User



Situational Awareness, ISR,  
Kinetic and DE Targeting & Tracking



Atmospheric Data and Effects



Targets and  
Weapon Effects on Targets





# Wavefront Compensation



## Current Capability

- **Beacon Illuminator Lasers**
  - Currently available higher power beacon illuminator lasers may limit beam combining approaches (e.g. SBC)
  - Good  $M^2$  ( $\sim 1.2$ ) a requirement
- **Wavefront Sensors**
  - Currently focused more on incoherent sensing methods (SH-Pyramid, etc)
  - Performance not limited by well depth, but instead limited by noise performance ( $\sim 40e^-$ ), frame rates ( $< 2$  khz full frame)
- **Deformable mirrors**
  - Significant portion of stroke consumed to attain static flatness ( $\sim 250$ nm), due to coating induced deformation
  - 4-12  $\mu$ m stroke

## Needed Capability

- **Beacon Illuminator Lasers**
  - Higher power lasers close to  $1\mu$ m, but which do not interfere with SBC based systems
  - For coherent approaches, transform limited pulses or highly coherent chopped CW in imaging wavelengths, highly diverged for imaging entire FOV.
- **Wavefront Sensors**
  - Sensors more suitable to coherent sensing and wavefront compensation (e.g. digital holography) with higher well depth, 40 khz frame rates, full frame
- **Deformable mirrors**
  - Good unpowered surface flatness,  $< 50$ nm
  - 6-18 $\mu$ m stroke

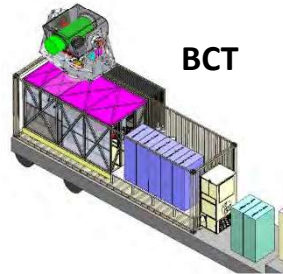
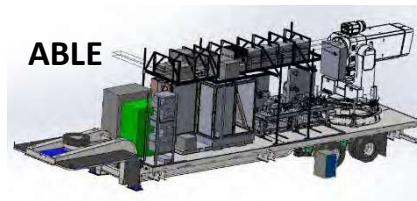
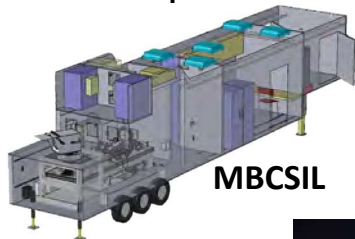


# Demonstration and Field Testing



## Current Capability

- Very limited field testing of HEL systems against supersonic targets at ranges relevant to service missions.
- Numerous Service HEL testbeds exist; however, none are currently configured to perform autonomous engagement and prosecution of supersonic targets.

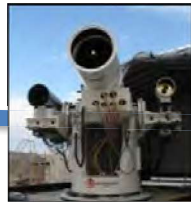


## Needed Capability

- Establish partnerships between DE JTO and the Services to use existing Beam Directors, BC Testbeds, and range facilities, to the maximum possible extent, to integrate key components and conduct the field demonstrations of autonomous engagement of supersonic targets.
- Organize and conduct an Integrated Tracking Test to demonstrate:
  1. Autonomous Engagement
  2. Target detection and acquisition at long ranges;
  3. Handover to the fine tracker; and
  4. High bandwidth tracking and aimpoint selection and maintenance in relevant environments



# DE-JTO Joint Laser Deconfliction Safety System



USN  
CPASS, EPASS  
2009



Maritime Dynamic Tracking  
2010-2011



EPASS  
2012

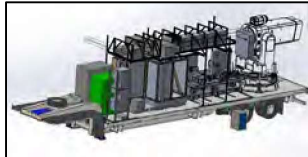
## LAWS



QRC HPASS  
2014-2017

- Outside Programs requesting HPASS:
- GBAD (authorized Jun 2015)
  - DLWS/HELLADDS
  - ATHENA
  - HEL-MD
  - DARPA-Endurance

- JLDSS Phase 1 – HW/SW Solution
- SPAWAR
  - ABLE Program



ABLE

Initial Decentralized Deconfliction Code



DSS integrated with ODIN and HELIOS  
2017-2018



DSS Centralized and

Decentralized Code Complete, V1.2.0.2  
2019-2021

MDA: GA  
RCCTO: NG, Kord

## 2022

Goal: Automated Software Solution

**CPASS:** Centralized Predictive Avoidance Safety System  
**DSS:** Deconfliction Safety Software  
**EPASS:** Enhanced Centralized Predictive Avoidance Safety System  
**HPASS:** Hybrid Predictive Avoidance Safety System

**ABLE:** Advanced Beam Control Locating and Engagement  
**HELIOS:** HEL and Integrated Optical-dazzler with Surveillance  
**HELMTT:** High Energy Laser Mobile Test Truck  
**ODIN:** Optical Dazzling Interdictor, Navy



# Summary



- **DE JTO experienced a drastic cut to the FY21 budget forcing changes to existing JTO processes and re-prioritization of funded activities**
  - Keep the office open and stream-line processes – highest priority
  - Fund Beam Control and Fire Control technologies required by missions that OSD HELSI products enable – high priority
  - Postpone HPM and other technology development efforts
- **DE JTO assures relevancy via close coordination of DEW investment planning with OSD(R&E), the DEW Col and Service & Agency DE leadership**

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**BACK-UP CHARTS**

**Dr. Lawrence Grimes, Director  
23 March 2021**



# Overview



## DE JTO Purpose



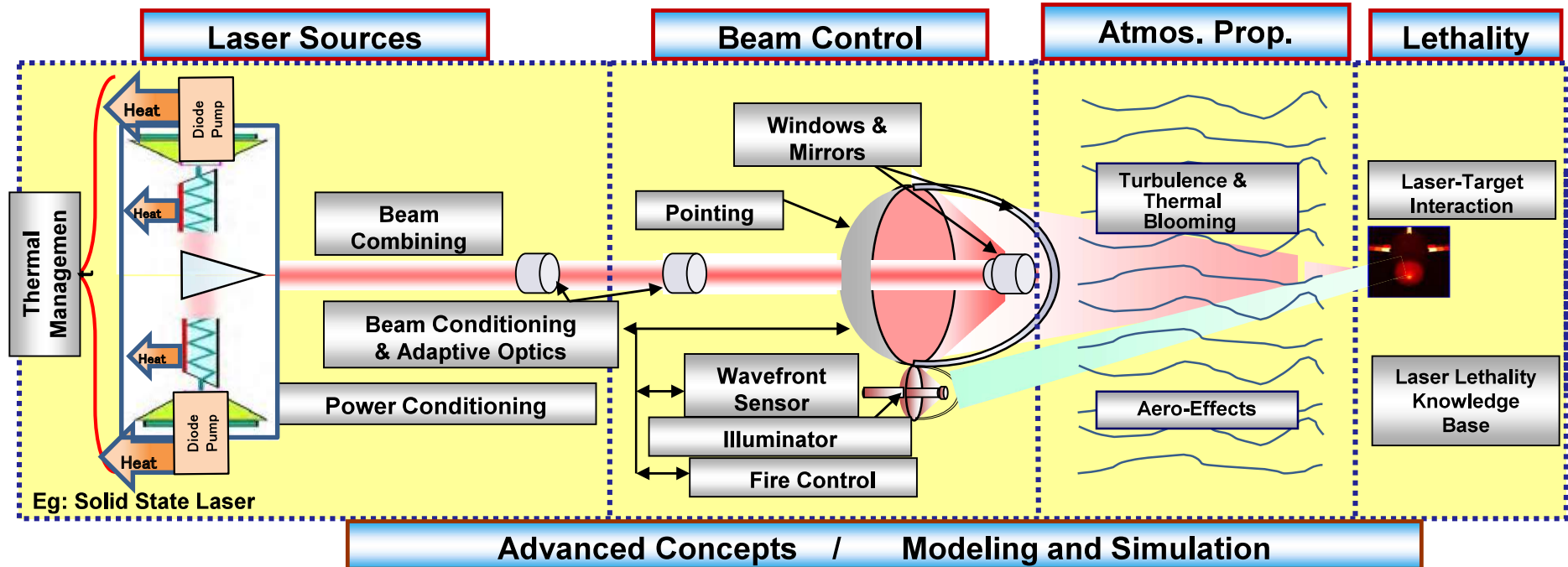
- Develops technology required by the Services
- Pursues high-risk, high payoff technologies for HEL community
- Provides focus for multi-Service technology requirements
- Facilitates transitioning technology from the lab to warfighter

## Accomplishments

- HEL JTO and now DE JTO has been advancing DE technologies with multi-Service & Agency (S&A) uses since 2001
- DE JTO declares success of a technical project when another organization either uses the project result or continues the development of the project
- DE JTO Investments in Laser Weapon subsystems have enabled Service demonstrations
- *DE JTO has prioritized investments in Beam Control and Fire Control technologies required by the missions that future multi-100kW lasers enable*



# HEL Weapon System (HELWS) Anatomy



DE JTO Technology Area Working Groups (TAWGs) guide S&T investments:

- TAWG Quad Chart Links
- [Laser Sources](#) – BAA, S&A, and MRI funding
  - [Beam Control](#) - BAA, S&A, and MRI funding
  - [Advanced Concepts](#) - BAA, S&A, and MRI funding
  - [Atmospheric Propagation](#) – Directed funding
  - [Lethality](#) – Directed funding
  - [Modeling and Simulation](#) – Directed Funding
- Directed Projects: JHPSSL, RELI, JLDSS, GDS, ABLE, ...



# Technology Maturation Must Lead System Development



Technology Maturation Periods	Missions			
	Now	Near Term	Mid Term	Far Term
Technology Maturation / Timeframe	TRL $\geq$ 5	TRL 3-5	TRL 2-4	TRL 1-3
	Current SoA	0-3 Years	4-7 Years	8-10 Years
System Description & Conditions	<b>Demonstrators</b>			
	<b>Increasing Operational Capability</b>			
	<b>More difficult targets, scenarios, and environments</b>			
	Entry Level HEL LWS; Basic Target Set	100KW Class; Spiral Upgrade; Next Gen System	500 KW Class; More Robust Targets; Increased Ranges	1MW Class; Most Difficult Targets Sets; Extreme Ranges
System Development Timeframe	0-3 Years	3-5 years	8-10 years	>10 years
Other Improvements	Improvements; SWaP; RMA			



# Beam Control Development for High Energy Lasers



## JTO Development


- Stabilized Fast Steering Mirrors (FSMs)
- Adv Image Tracking Algorithms for BC
- LaWS Multi-Beam Director
- Tactical HEL Wpn. Alignment Sys Arch
- LOS Control with Adaptive Disturbance Estimator Feed Fwd
- Deformable Mirrors
- Small LWBD Demo
- HEL Adaptive Optics
- Adv Image Tracking Algorithms for Beam Control
- HW and SW Framework for Tracking Systems
- Development/Evaluation of Hybrid Tracking Tech
- Tracking Through Aero Optic Disturbances
- ABLE Testbed

### Future Directed Projects


- Adv Tracking Algorithms
- Wavefront Sensing
- **Autonomous Engagement**
- **Path Characterization System**

## Sub-System Demos

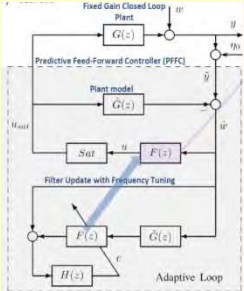
### FSMs




### Advanced Tracker



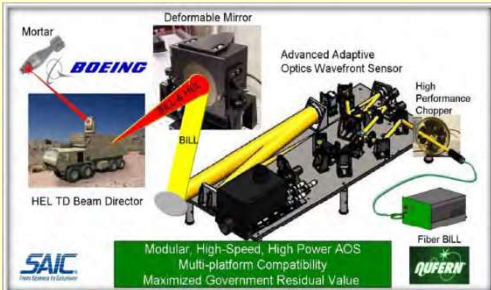
### Predictive FF Control



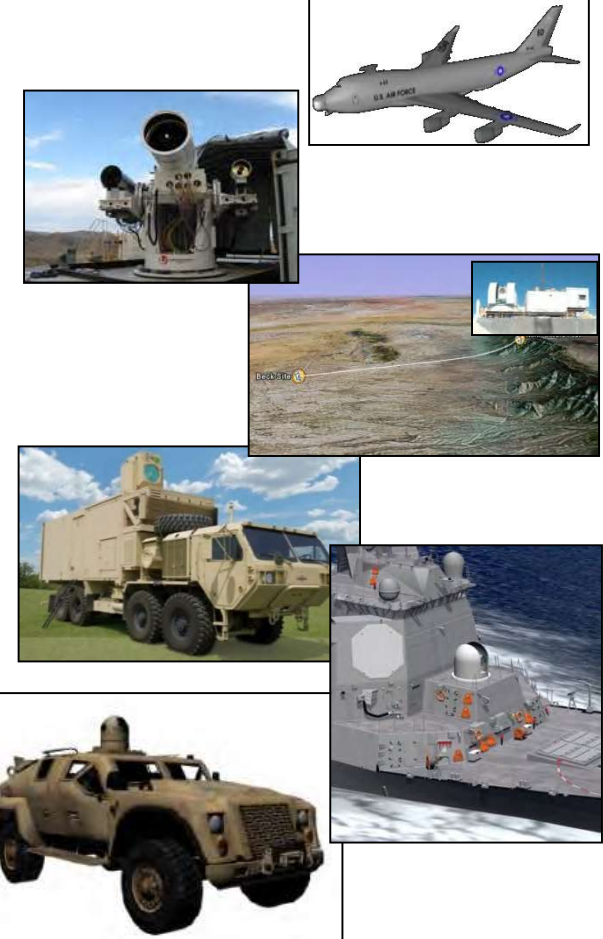
### GBAD LWBD Demos



### AO: Future Integration



## S&A Demonstrations



2001 to 2017



# Laser Sources Technology Assessment Review (LSTAR)



## Platform Sizing

	kg/kW	l/kW
L	20+	40+
M	<15	30
S	<10	20



	<100 kW			100 - 300 kW			300 - 500 kW			500 kW - 1 MW			
	L	M	S	L	M	S	L	M	S	L	M	S	
<b>Front end</b>													
Laser source & EO Modulator	Green	Green	Green	Green	Green	Green	Green	Yellow	Yellow	Yellow	Red	Red	Red
Low power amplifier stages	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
<b>Power Amplifier</b>													
Bright diode pump modules	Green	Green	Green	Green	Green	Green	Green	Yellow	Yellow	Yellow	Red	Red	Red
High temp diodes	Yellow	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Red	Red	Red
Pump+signal combiners	Green	Green	Green	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Red	Red	Red
Advanced gain fibers	Green	Green	Green	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Red	Red	Red
High power isolators	Green	Green	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Red	Red	Red
Delivery fiber + end cap	Green	Green	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Red	Red	Red
<b>SBC Component</b>													
Linear fiber array holder	Green	Green	Green	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Red	Red	Red
SBC Optics	Green	Green	Green	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Red	Red	Red
SBC Reflection gratings	Green	Green	Green	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Red	Red	Red
Advanced transmission gratings	Green	Green	Green	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Red	Red	Red
<b>HEL System</b>													
Thermal Management	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Red	Red	Red
SWAP	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Red	Red	Red



# JTO Advanced Beam Control for Locating and Engagement (ABLE)



## Enhanced Tracking System (ETS)

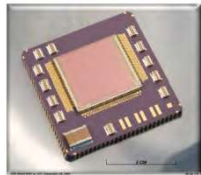
### Advanced Trackers



Gimbal & BDA



TIL Technology



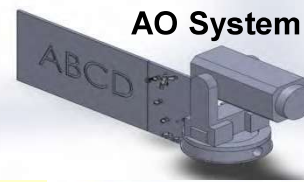
Low Noise & High Speed FPA

- Long-range target location, ID, aim point selection and maintenance
- Advanced tracking camera
- Tracking Illuminator Laser (TIL)
- Advanced tracker

## ABLE Advanced Beam Control Demonstration



Advanced Algorithms

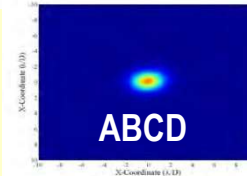


AO System

### BIL Technology



Track Only



ABCD

- Long range beacon
- Deep turbulence compensation
- Advanced Adaptive Optics (AO)
- Beacon Illuminator Laser (BIL)
- Advanced wavefront sensing

## ABLE Integrated System Demo

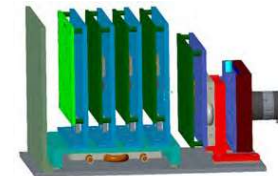


ABLE Test Bed

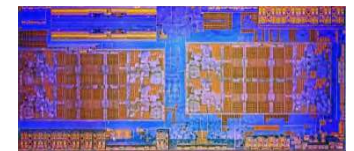


SHEL

### 3D APD Camera



### 3D Tracker



- Integrated test bed
- Beam director / gimbal
- Controllers
- ETS
- ABCD
- Surrogate HEL
- 3D Tracker

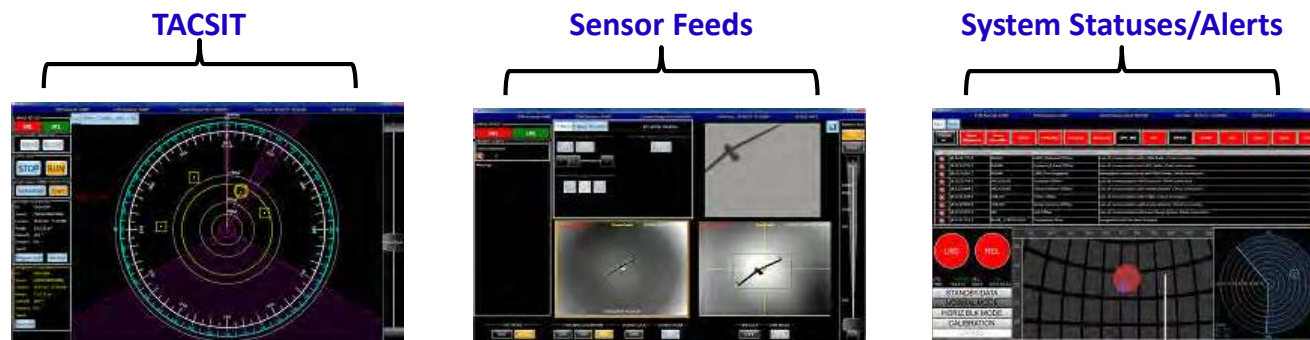
2015 to 2020



# Laser Weapon System (LWS) Console – Deployed on USS Ponce\*



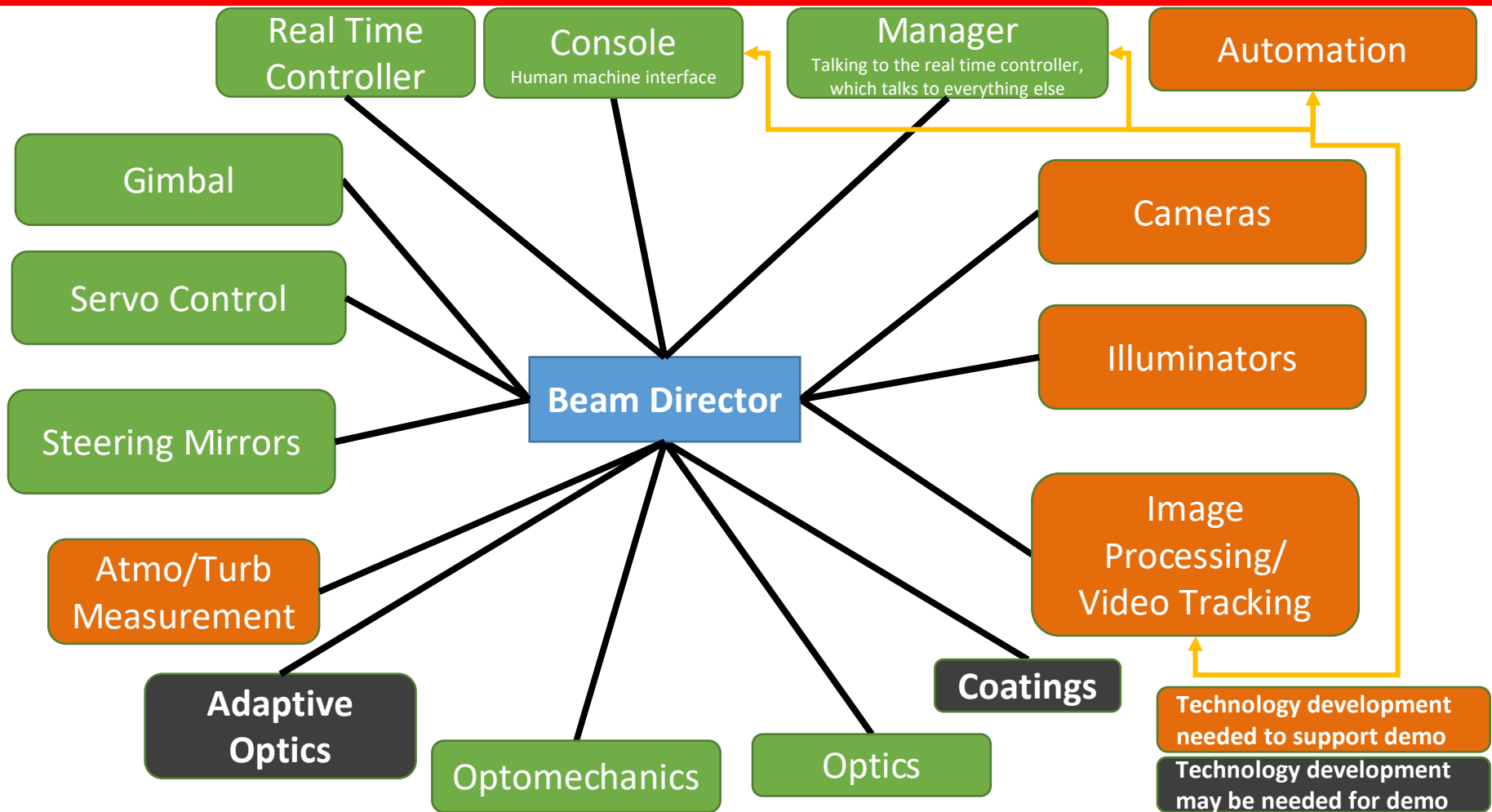
- **Three simultaneous feeds of data containing**
  - Radar contacts / Tactical Situation (TACSIT)
  - Multiple LWS sensor image feeds with manual sensor/tracker control
  - System status, and predictive avoidance feedback
- **Operator wears headset, works hand controller and foot pedals**
- **Operator is cognitively saturated during engagement, and this adds to engagement timeline**
- **Too much manual operation for short timeline engagements – automation is critical**



\* System is largely similar to that currently on the USS Portland



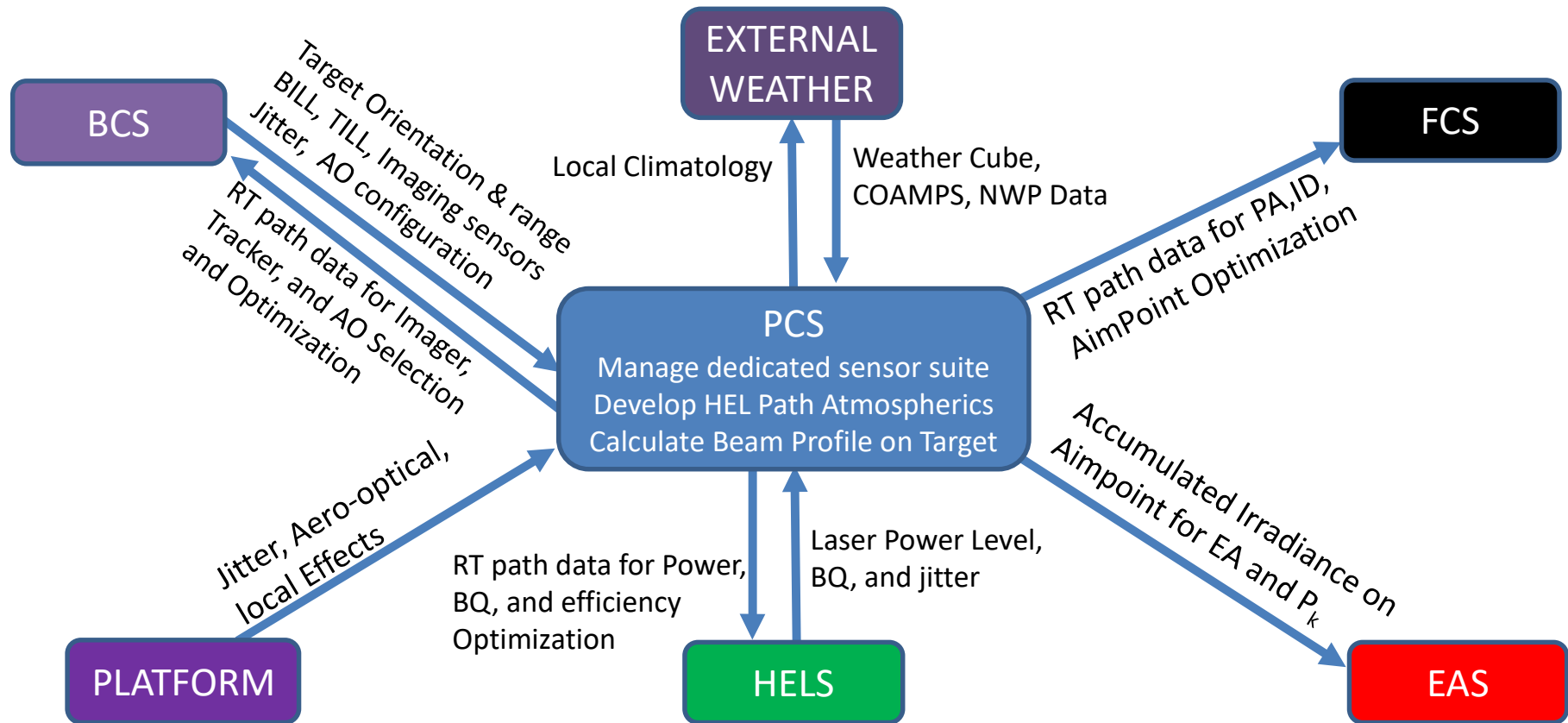
# Beam Control Universe



Beam Control (BC) is the product of multiple contributors; Development may be needed in all areas, but a few critical areas should be near term focus to overcome critical functional gaps in achieving a successful demo-after-next



# Path Characterization System (PCS) Functions and RT Data Flow





# High Power Microwave – Program Summary



## Technical Investment Approach

Invest in cross-service gaps in any/all below:

- Effects Understand, quantify advanced HPM weapon effects
- Modeling Use modeling tools to develop & optimize subsystem designs all the way through EM weapon effectiveness
- Power Develop compact Pulsed Power materials, components & subsystems
- Sources Create/optimize/revolutionize sources of HPM (SWaP and efficiency)
- Deliver Deliver energy (improve antennas/radomes, sources) to neutralize targets: understand fundamentals of radiation, propagation and coupling

**Current priorities: Understanding of Rep-Rate effects, wideband/ultra-wideband effects and/or alternative carrier frequency effects; advanced sources (nonlinear transmission lines); Modeling of power electronics in support of Pulsed Power; Antenna/Radome optimization (SWaP, low sidelobe, conformal)**

## Benefits

**Capabilities of ground-based, ship-based, airborne and podded HPM weapons:**

- Low collateral damage (reduced political and reconstruction costs)
- Non-lethal (reduced casualties and associated political costs/restraints)
- Re-useable, deep magazine, multiple targets per sortie (cost effectiveness)
- Counter-technology –defeat adversary’s information technologies

**High Power Microwaves: One weapon to engage multiple targets taking out communications, computers, C4I and other electronics, CMs, UASs with low collateral damage.**



Aerial HPM Concept Image



Raytheon's Phasor System



ARL L-Band Source